

Detector R&D or R&D for Future Detectors

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- The next big detector projects
- Challenges for detector developments
- Review of the state of the art in main detector areas

The Next Generation

The Big Detectors of the Future:

- Linear e+e- Collider Detector
- Hadron Collider of the next generation: SLHC
- Muon Collider?

Worldwide consensus has emerged, that Linear Collider is the next big facility to be built!

I will not talk about:

- LHC detector developments
- Tevatron detector developments
- other “approved” projects

I will concentrate on

- detector systems and different options
- some technological developments
- future R&D directions

Challenges

Where are we?

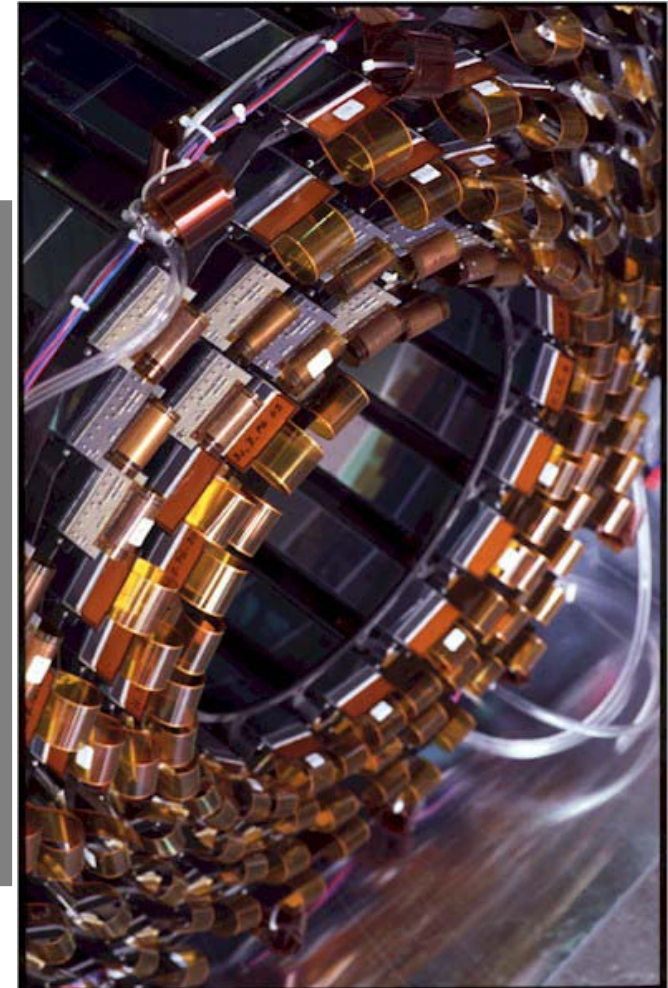
Enormous R&D done for Tevatron and LHC:

- lots of new technologies
- lots of new developments

Focus of these developments:

- Radiation hardness
- Speed (deal with huge occupancies)
- Achieve reasonable precision
- cost reduction

What are the main challenges in the future...???



CMS SI wheels

Lepton vs Hadron Machines

A very simple minded look at

Linear Collider

Small occupancies

Small backgrounds

Small rates

Extreme precision

Focus on individual particles

Hadron machines

Huge occupancies

Huge backgrounds

Huge rates

Reasonable precision

Look at ensembles

Challenges of Detector R&D:

- develop precision detector technologies
- develop technology and techniques to harvest the power of an LC
- prepare for a new radiation challenge at SLHC

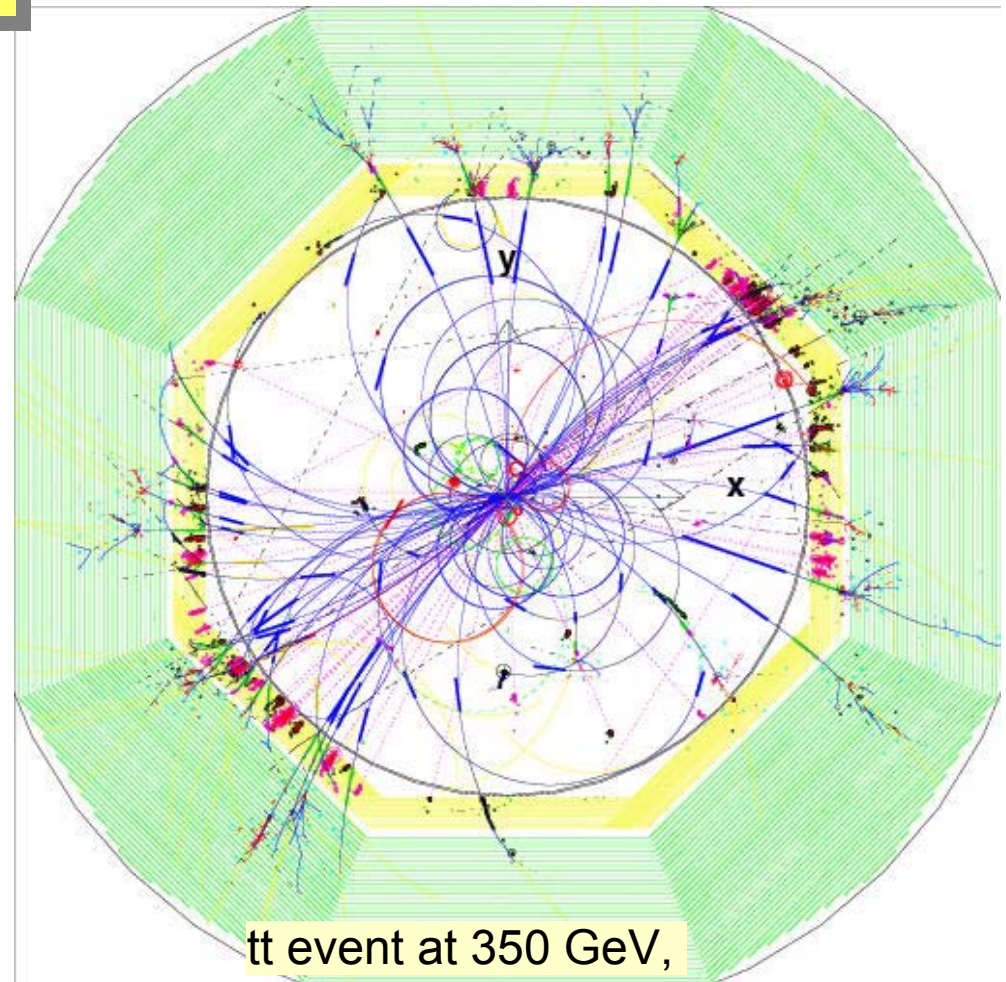
Detection at a Lepton Collider

Reconstruct the 4-momentum of all particles (charged and neutral) in the event

- individual particles
- charged and neutral particles
- system aspect stressed rather than individual sub detectors

Concept is being pushed at lepton collider, but is not limited to this

“Trade-name”:
Energy Flow (misleading)
Particle Flow



Particle Flow

Why particle flow:

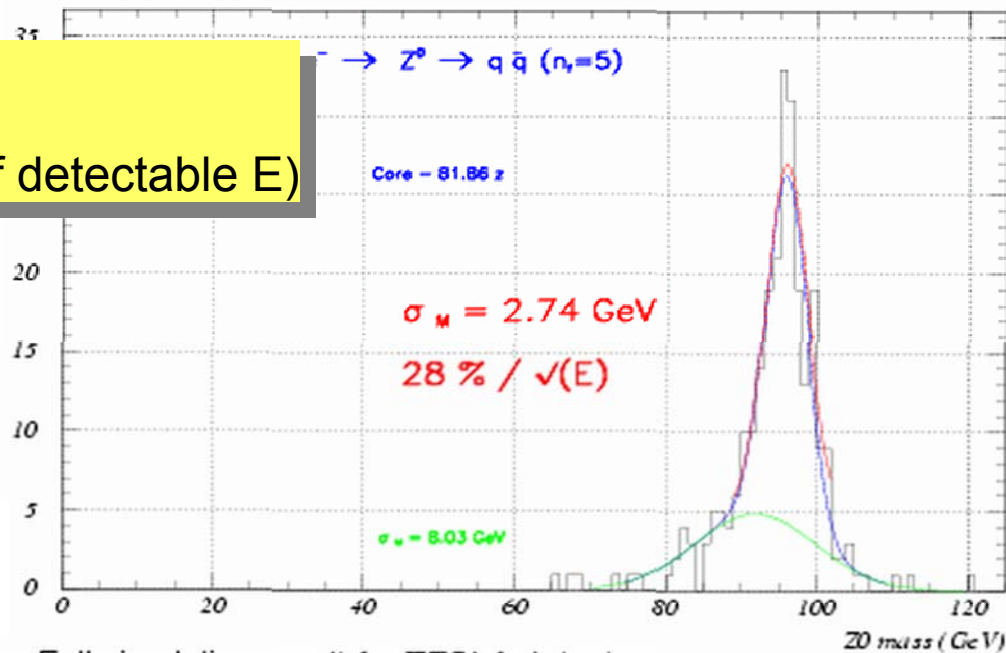
e+e- hadrons events at 500 GeV:

Tracker	charged particles	60% E
ECAL	Photons	20% E
HCAL	Neutral Hadrons	10%
LOST	Neutrinos	10%

Charged particles and photons carry 80% of total energy energy able (90% of detectable E)

example:
reconstruction of Z0
decays using PFLOW

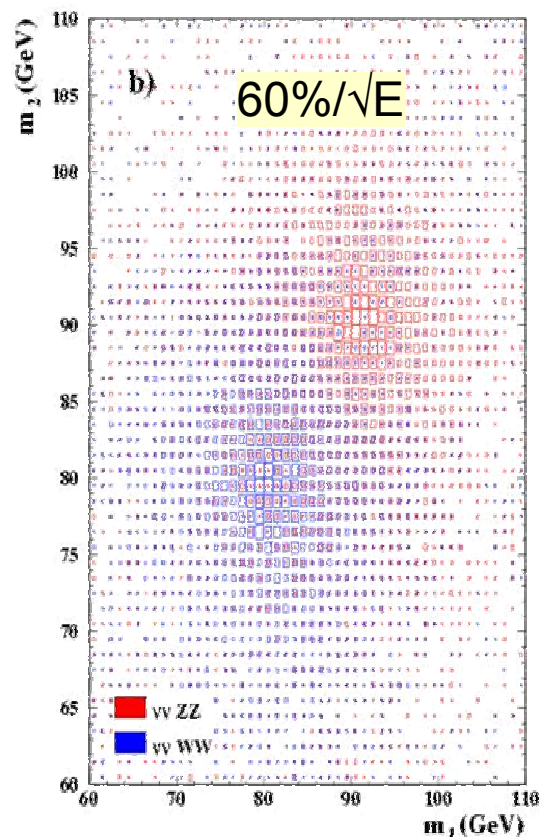
theoretical lower limit: $14\%/\sqrt{E}$
best achieved: $50\%/\sqrt{E}$ (Zeus)



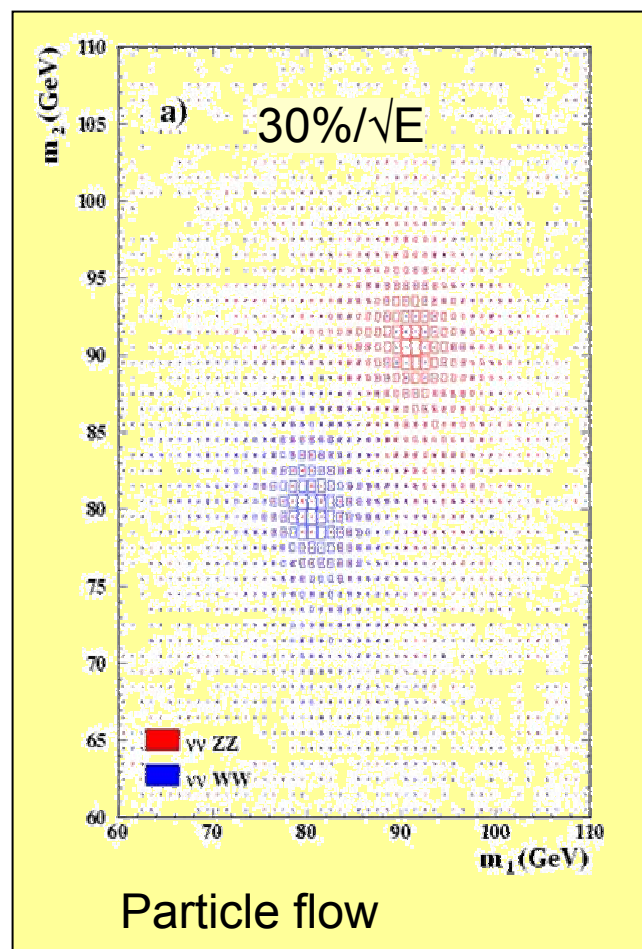
Physics Motivation/ Goal

Why is a new reconstruction concept needed?

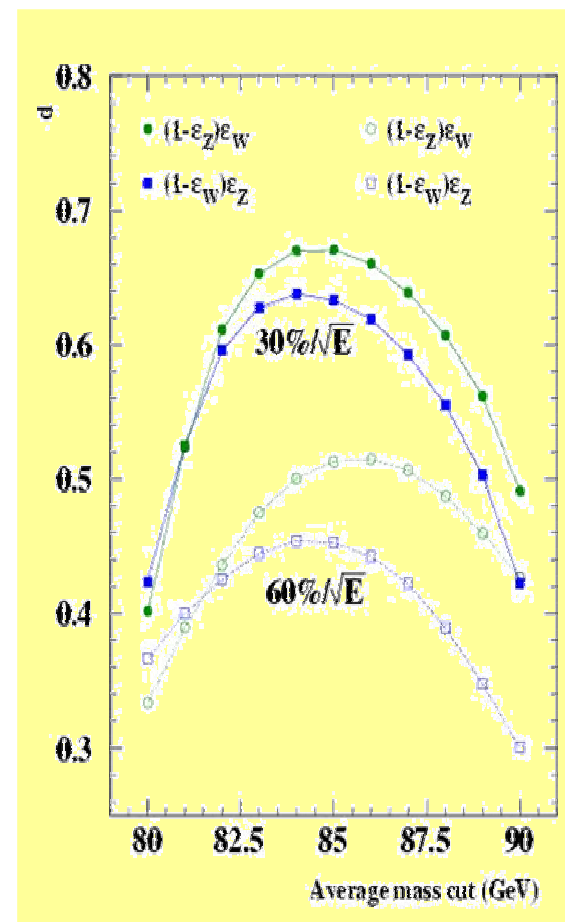
Need excellent capability to separate different final states
Example: W-Z separation (hadronic channel)



“traditional” methods



Particle flow



Detector Requirements

Particle Flow stresses:

- reconstruction of individual particles
- separation of particles (charged and neutral)

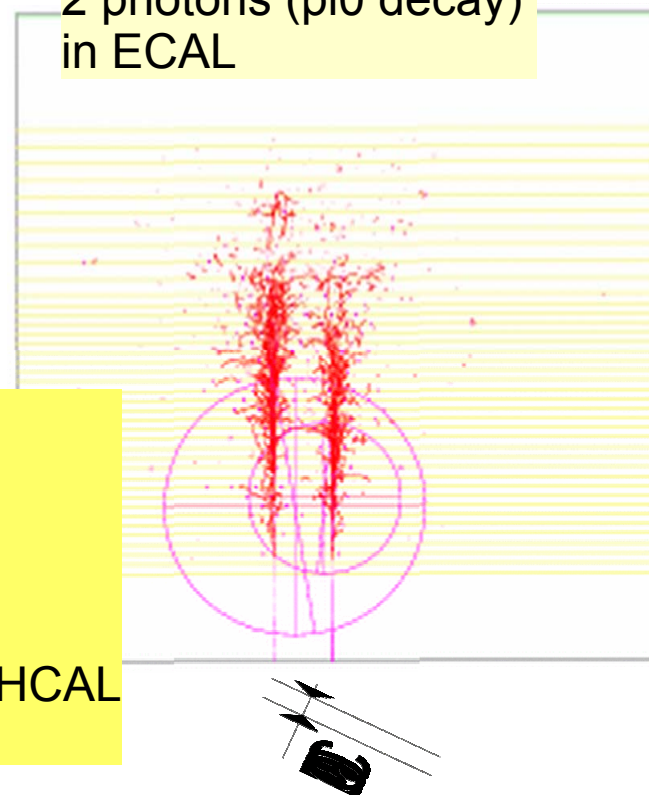
Less important:

- single particle energy resolution

Detector requirements:

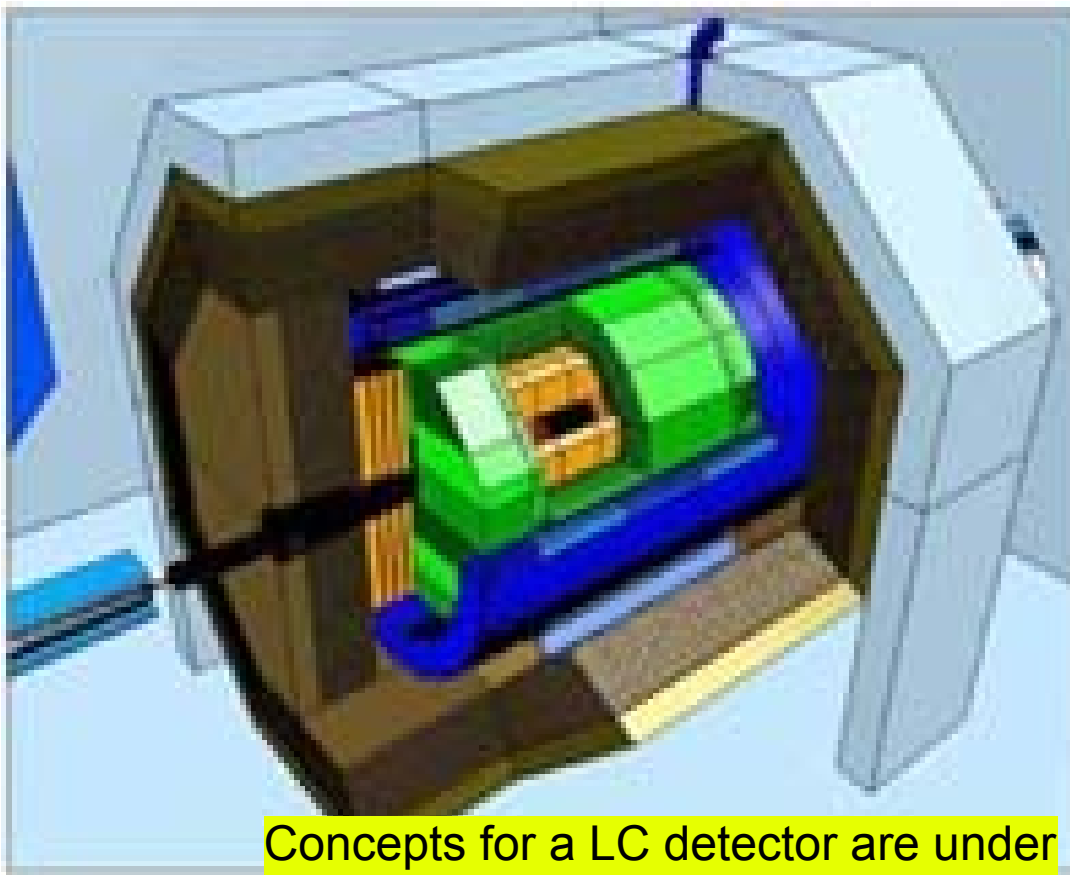
- excellent tracking, in particular in dense jets
- excellent granularity in the ECAL
- “no” material in front of ECAL
- good granularity in the HCAL
- excellent linkage between tracker – ECAL – HCAL
- excellent hermeticity

2 photons (π^0 decay)
in ECAL



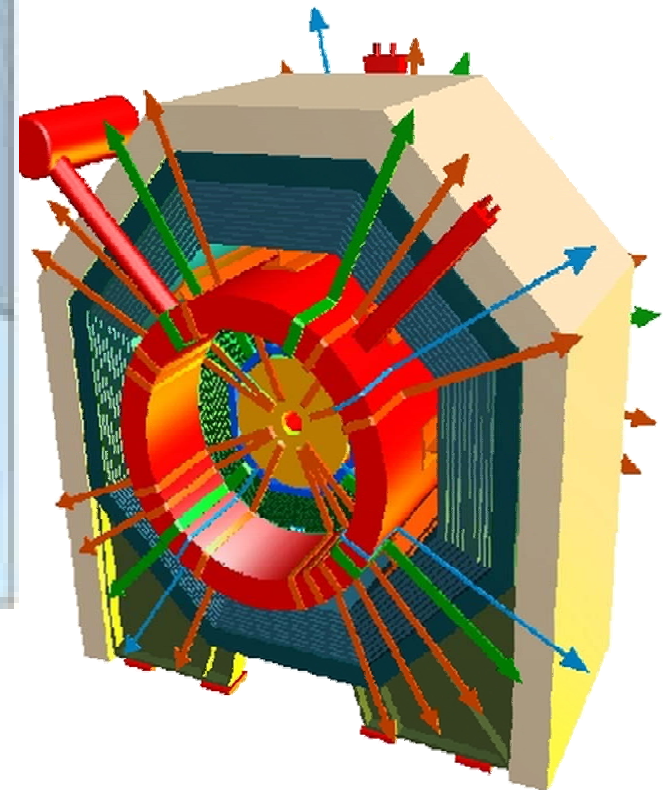
The LC Detector

LC Detector is general purpose detector, optimised for precision physics



Concepts for a LC detector are under development in
Asia – US – Europe

- excellent tracking
- excellent calorimetry
- both located inside magnetic field
- muon system



The Tracker Concept

- excellent track and momentum reconstruction
- outstanding vertexing
- very efficient tracking (particle flow needs to know about “all” particles)

traditional Approach:

- SI VTX detector: high resolution, 4-5 layers
- large volume medium resolution tracker (e.g. TPC) with many space points
- some additional detectors (intermediate tracker, endcap) to improve solid angle coverage etc.

“All SI” approach

- SI VTX detector: high resolution, 4-5 layers
- SI only tracking detector: few layers of good resolution

The Calorimeter Concept

- High granularity high segmentation sampling calorimeter as ECAL
 - SI-W ECAL seriously investigated
 - other more traditional options look at combining more standard ECAL technology (Scintillator tile) with few layers of SI

typical parameters:

- 1 x 1 cm² cells (Moliere Radius Tungsten 0.9cm)
- O(20 X0) thick with O(40) layers
- sampling ratio 1:3 to 1:6 depending on design
- 10th of millions of channels

- Highly segmented HCAL

- analogue Scintillator option
- “digital” option

Analogue: record position and energy

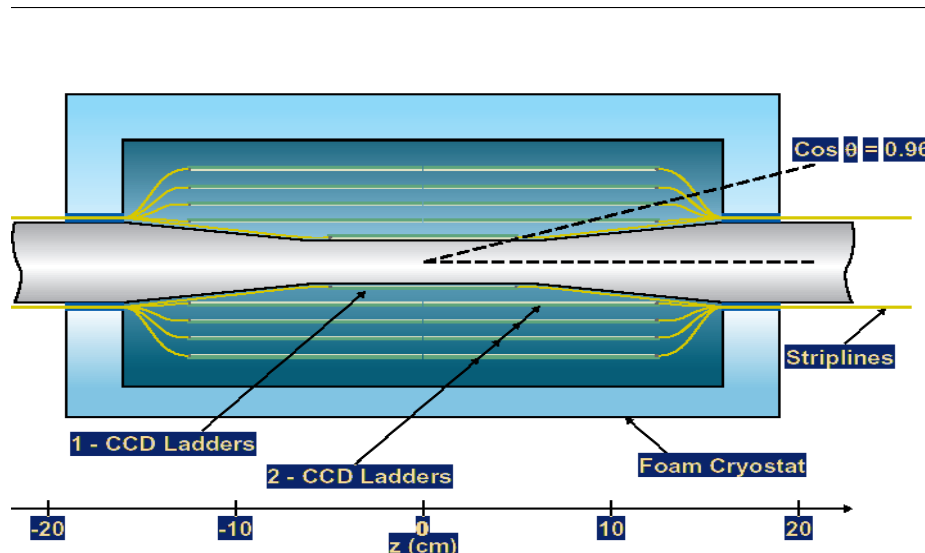
Digital: record position

typical parameters:

- 1 x 1 (digital) to 5 x 5 (analogue) cm² cells
- O(20 samplings)

The VTX Detector

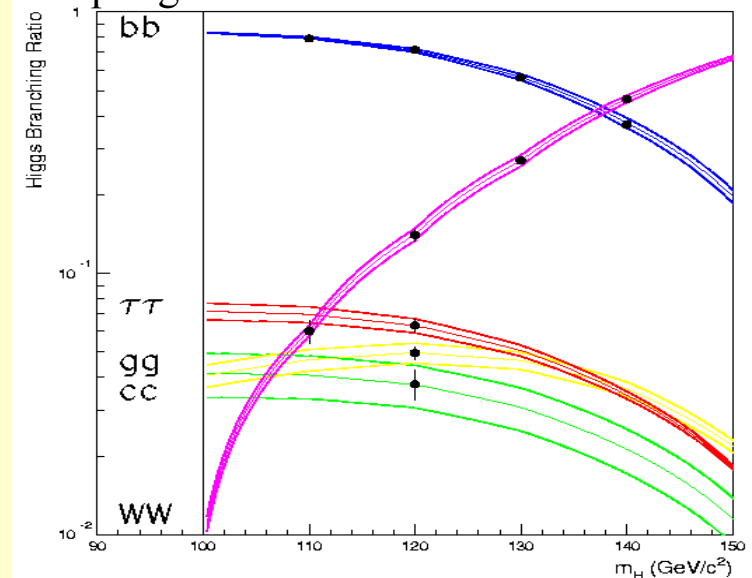
- High precision detector close to the beam pipe ($R(\text{min}) = 1.5 \text{ cm}$)
- Several technologies are under discussion
 - ➔ CCD based sensors (SLD technology)
 - ➔ CMOS based sensors (new development)
 - ➔ DEPFET sensors (new development)
 - ➔ FAPS
 - ➔ HAPS
 - ➔ others...



“generic” VTX layout

One of the most challenging jobs: H to fermions

Couplings to fermions:



VTX R&D Challenges

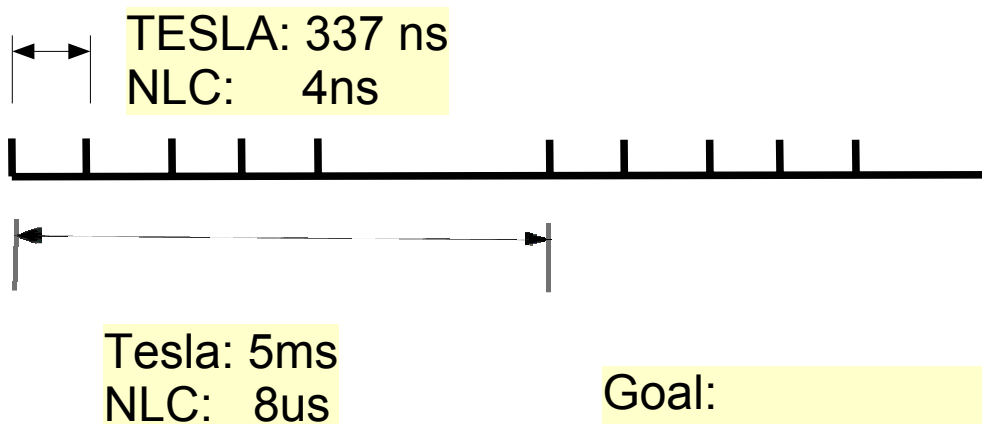
- for Linear Collider:

- readout speed
- material budget
- power consumption
- radiation hardness

- for hadron machines

- radiation hardness
- (see later in this talk)

typical LC time structure



Goal:

- minimise the number of bunches integrated
- high readout speed: 25-50 Mhz
- column parallel readout required

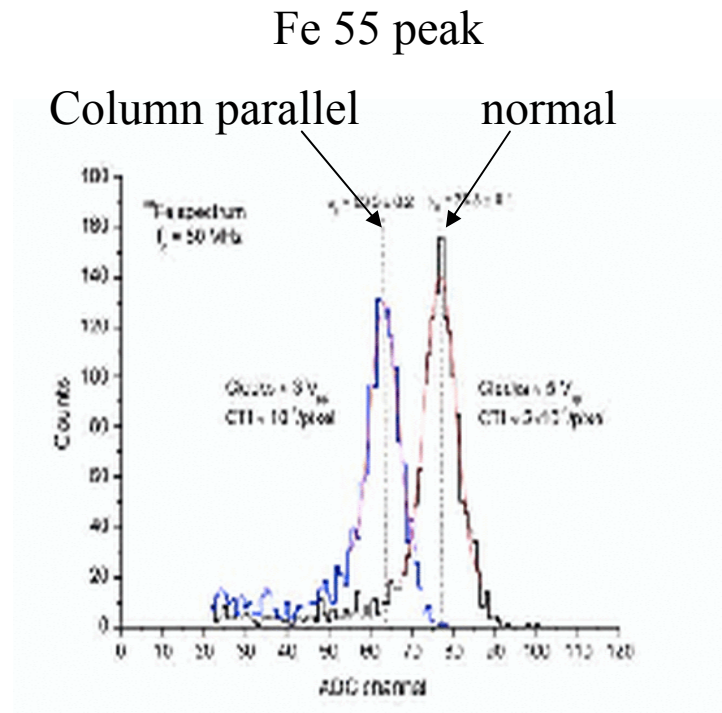
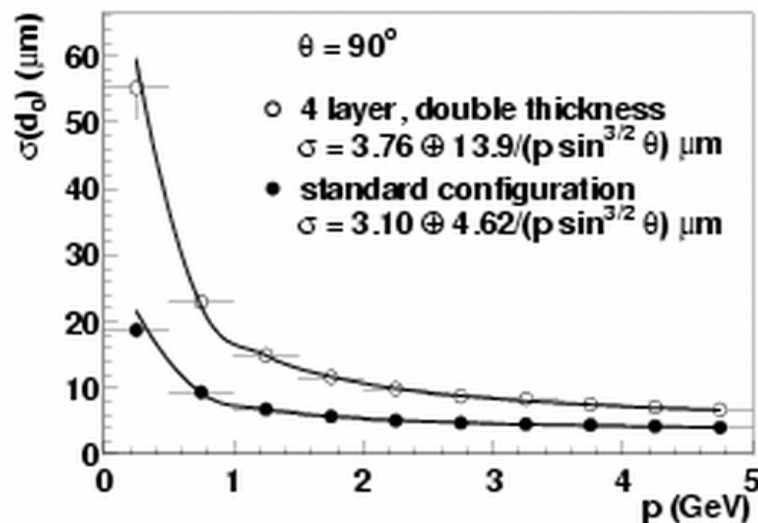
CCD Detector R&D

- principle of operation well proven (SLD VTX detector, others)

- Goals:

- ➔ readout speed: column parallel readout, 50MHz clock
first successful operation reported this summer at RAL

- ➔ excellent resolution: intrinsic resolution, mechanics, material budget



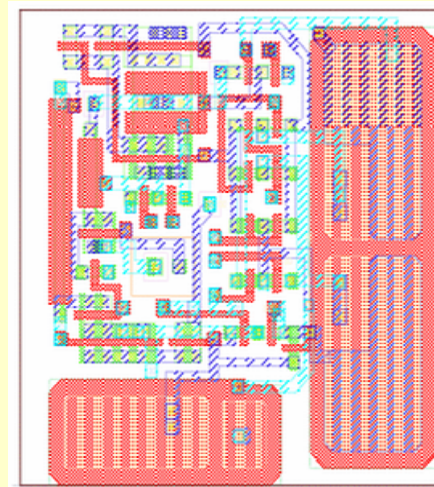
Thickness very important:
intense R&D effort to thin sensors in order to minimise the material budget.
goal: 50 μm thick sensors
<1% for complete detector

MAPS detector R&D

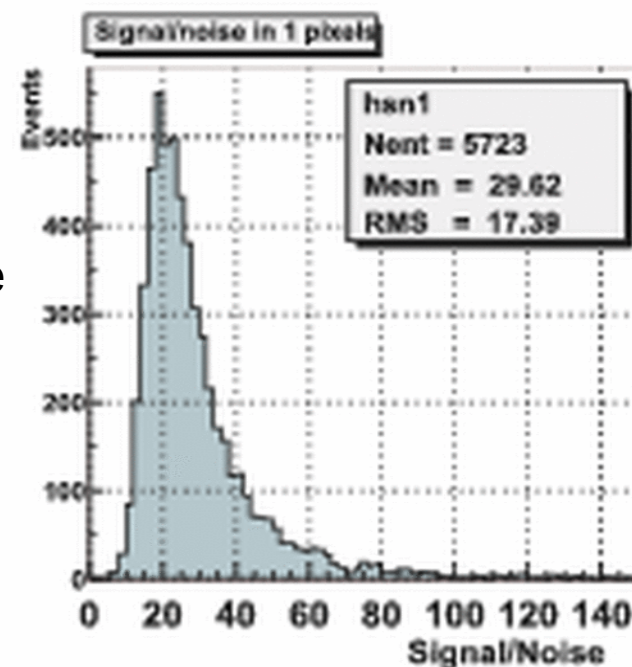
- MAPS: Monolithic Active Pixel Sensor
- Each pixel has some readout electronics integrated
 - operationally simpler than CCD
 - no clocking-out of charge: intrinsically radiation harder

but

- little experience as particle detector
- larger material budget (?)
- larger power consumption
- Final readout through chip on the edge of the device
- Intense R&D to develop working chip since 1999:
 - by now 6th generation of test chips
 - successful operation in test beams



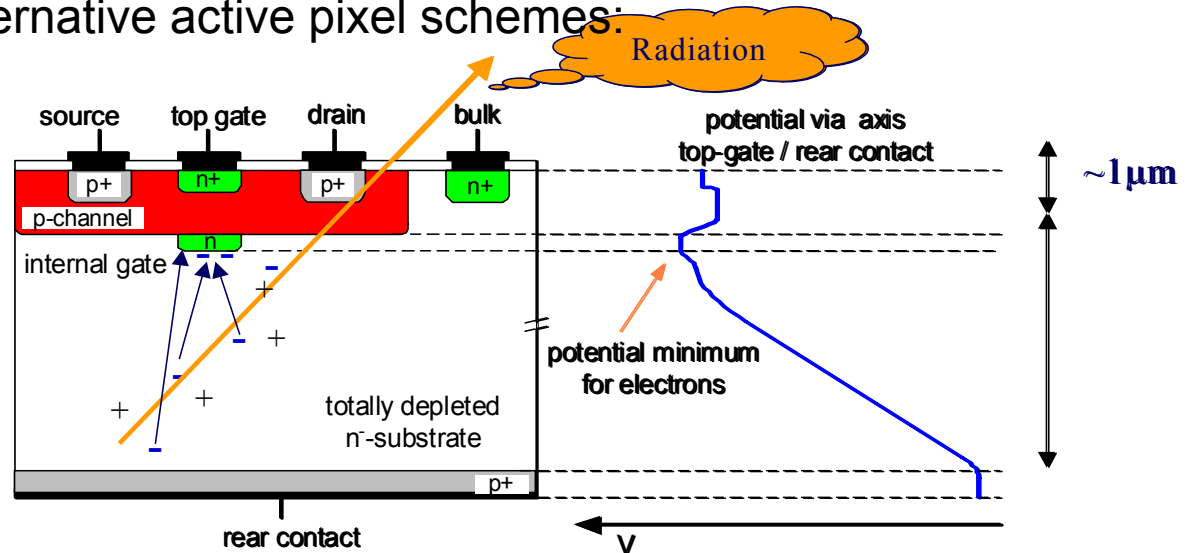
Single MAPS type pixel



DEPFET/ FAPS

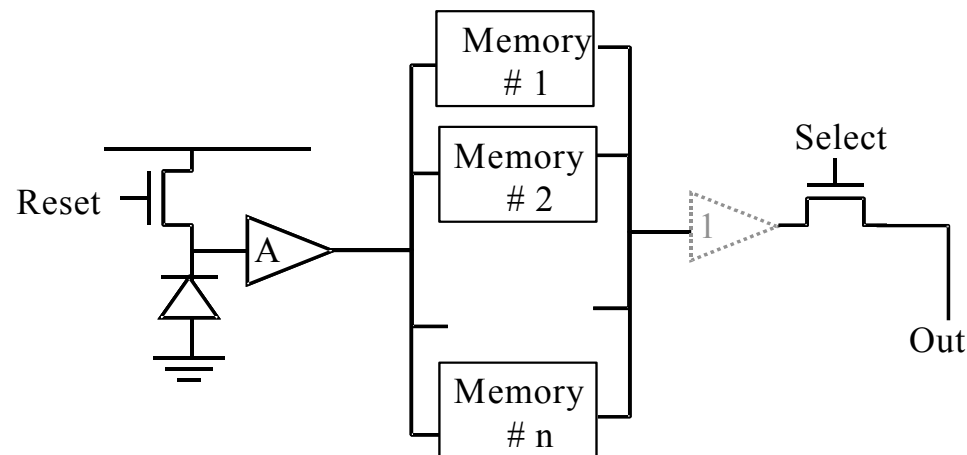
- DEPFET / FAPS: two alternative active pixel schemes:

DEPFET



FAPS:

similar to MAPS
but more than one
storage location on the
pixel

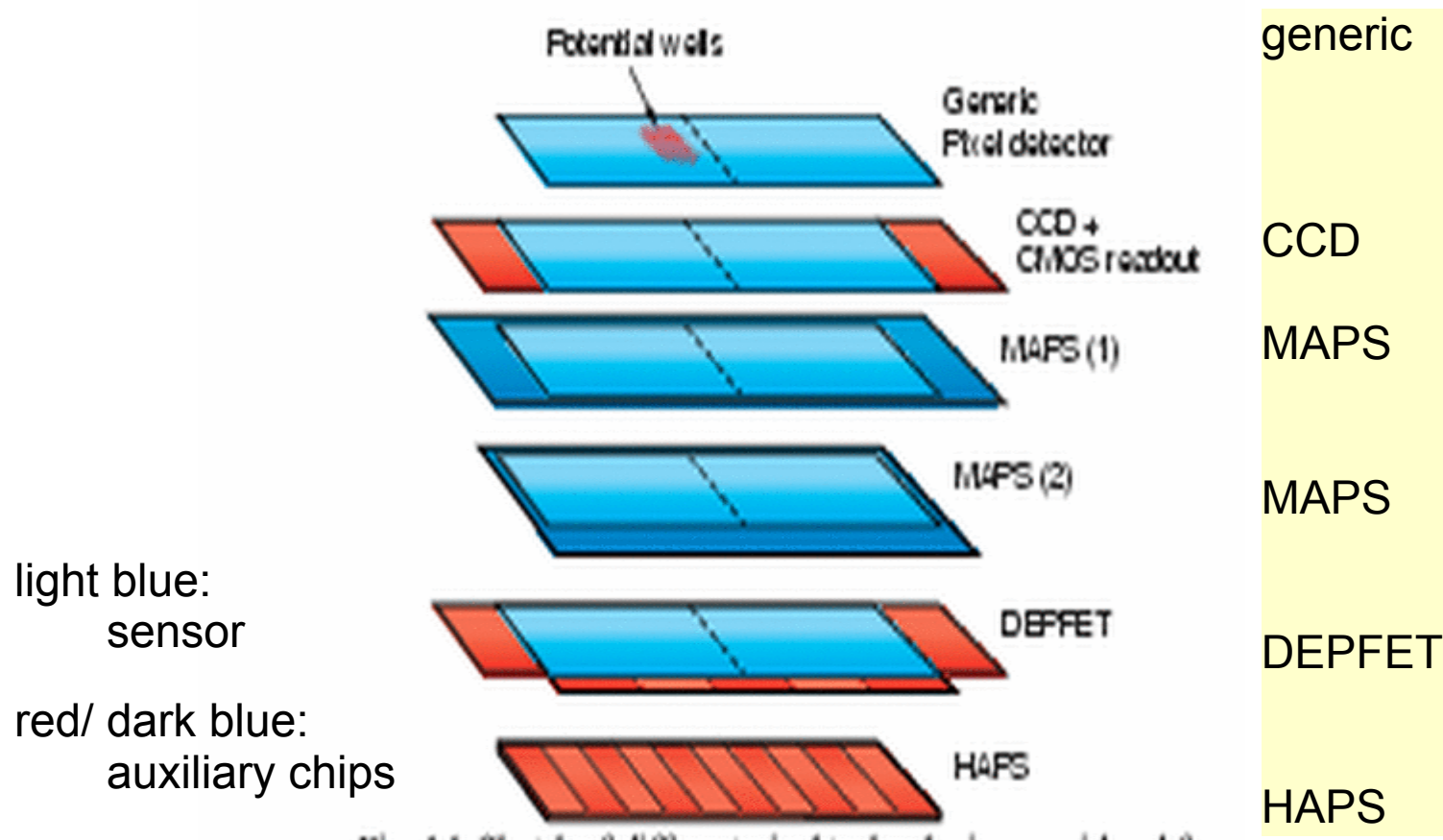


Both approaches look very interesting, but are at the beginning of development

Comparison of different options

Comparison is very difficult at this point: all technologies look promising

“Real Estate” comparison (source C. Damerell):



Tremendous activity, many exciting developments

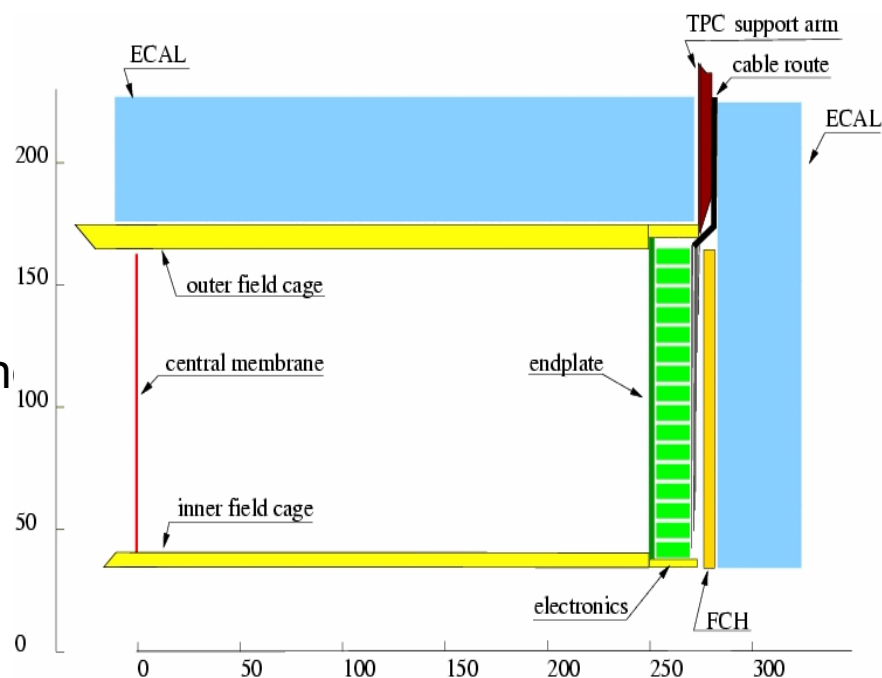
Tracking Detector

TPC as central tracker:

- many space points (200)
- good single point resolution ($O(100 \text{ } \mu\text{m})$)
- reasonable double track resolution ($O(\text{few mm})$)
- high redundancy results in excellent pat rec efficiency

R&D goals:

- develop new readout
- improve resolution:
 - charge collection
 - gas choice
- minimise material in field cage and endcap
- minimise power consumption of readout



TPC Readout

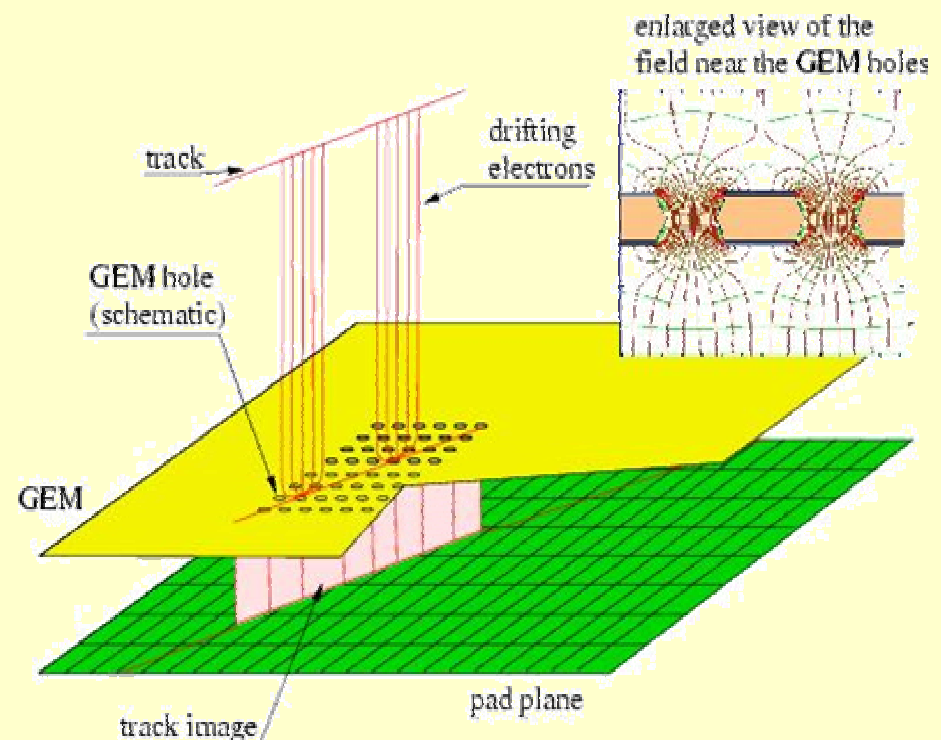
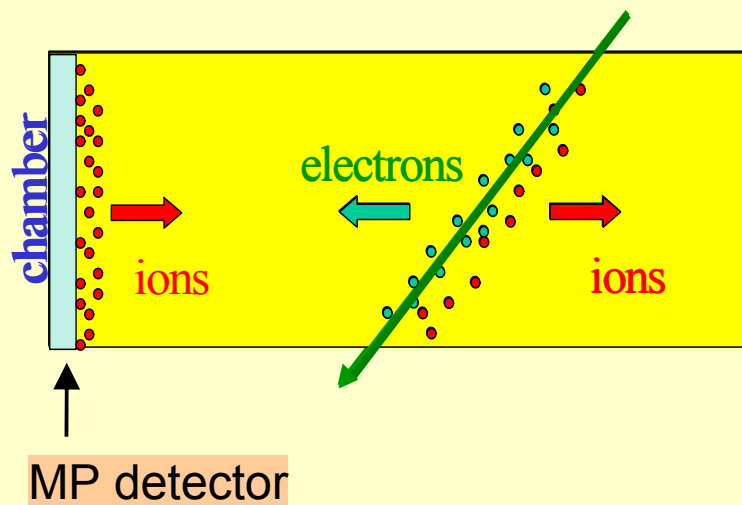
"traditional" wire chamber readout:

- Well understood, stable system
- "large" granularity
- Mechanically complicated
- Systematic effects through effect

Alternative solution:

- Based on micro-pattern (MP) gas detectors
- GEM/ micromegas
- Mechanically potentially simpler
- Less material
- Less systematic effects (potentially)
- Not yet proven in large scale projects

Principle of GEM TPC

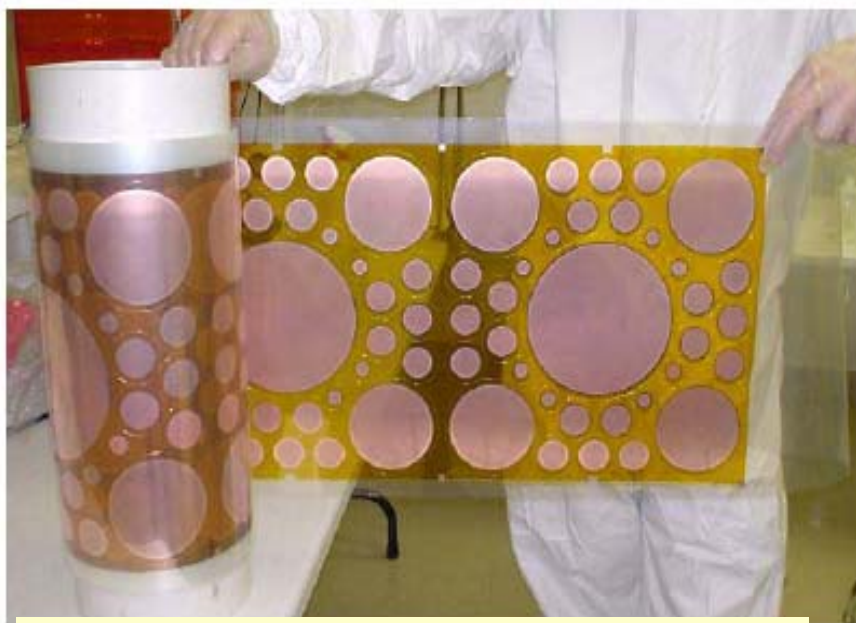


International TPC R&D collaboration: Europe – US - Canada

Micro Pattern (MP) Gas Detectors

GEM:

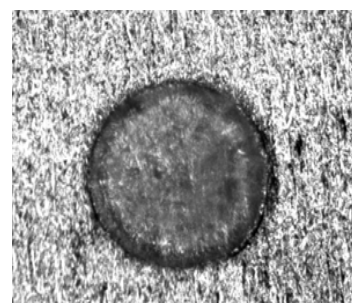
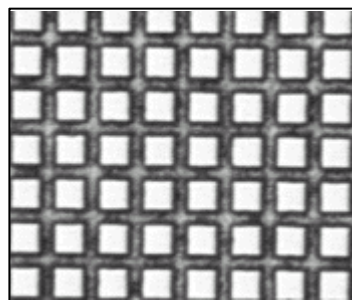
- Gas Electron Multiplier
- amplification in holes in a Cu clad Kapton sheet
- usually 2 – 3 stages



Example of mass produced GEM foil
(Purdue in collaboration with 3M)

MicroMegas:

- high field between mesh and anode provides amplification
- single stage



other
developments:

LEM:
Large Electron
Multiplier

Micro Dot
chambers

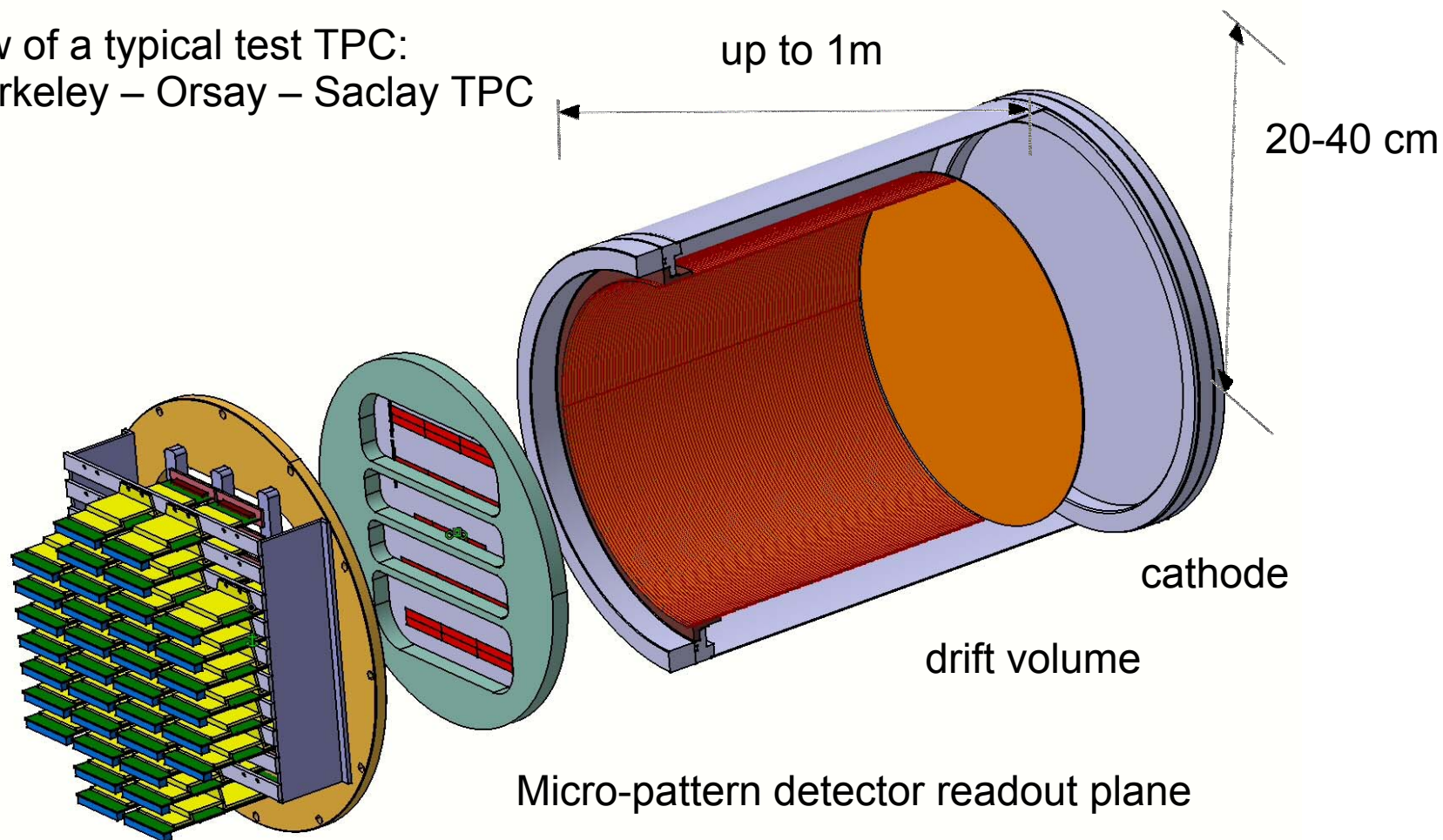
etc.

Intrinsic small length scale of these device allow:

- good 2-D resolution
- small systematic effects, in particular in B-fields

A typical GEM-TPC

3D view of a typical test TPC:
Berkeley – Orsay – Saclay TPC

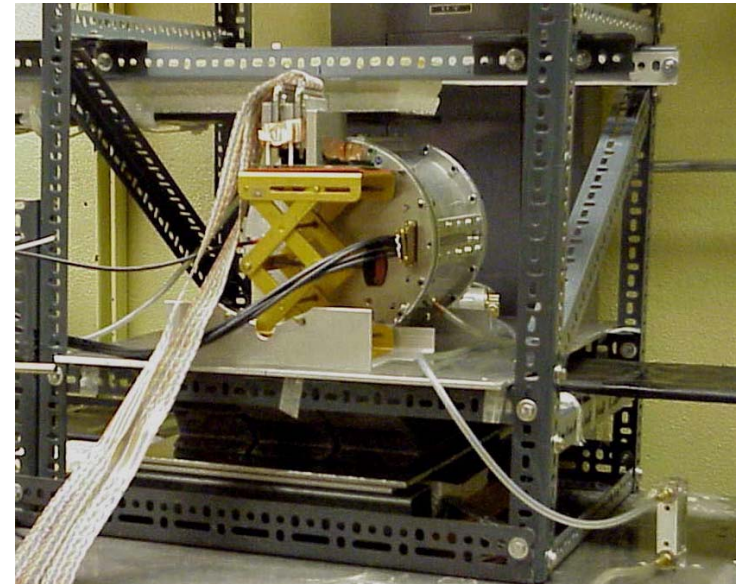
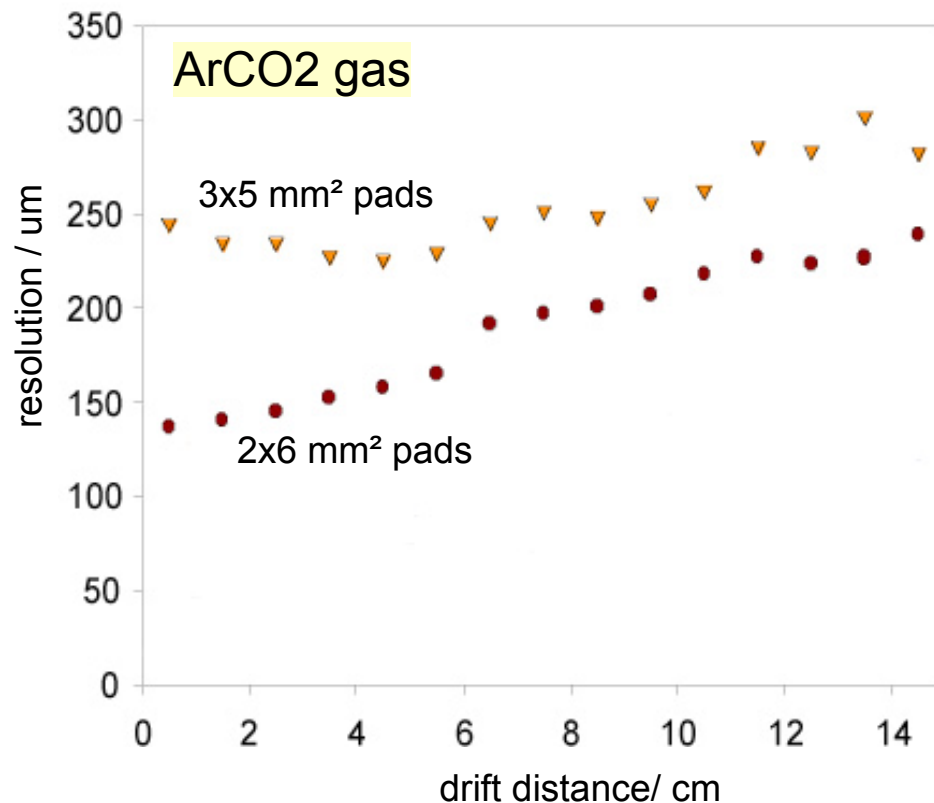


electronics (based on STAR experiment)

Performance of MP-TPC

- several test TPC's exist around the world
- first performance data are available without and with magnetic field

resolution vs drift distance, no B field



Investigate

- ➔ GEM properties
- ➔ resolution
- ➔ optimal method to pickup the charge

Performance in B-Field

- Most inner detectors are operating in a strong B-field

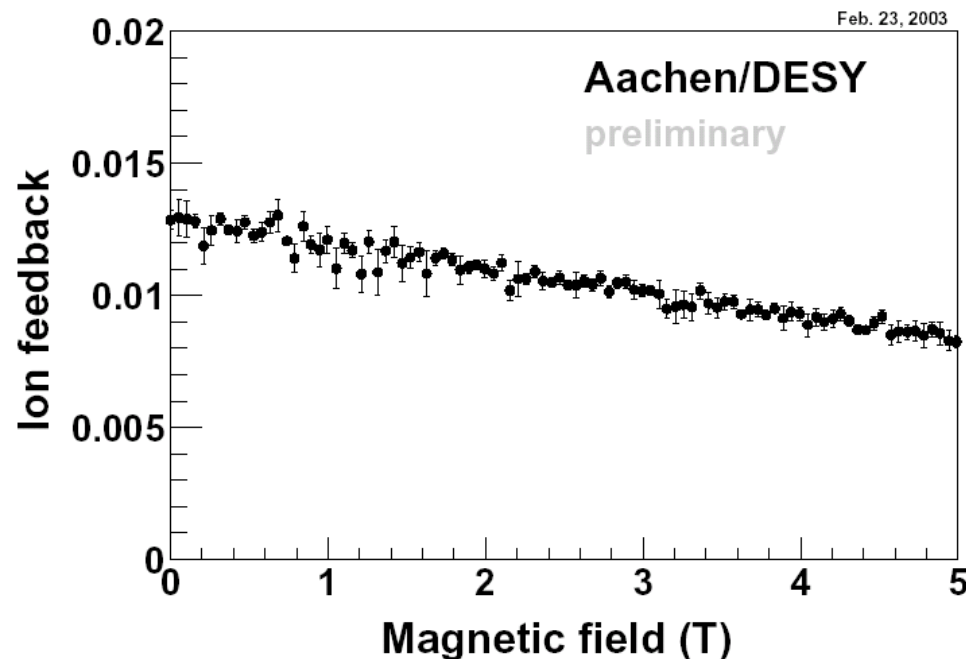
- existing detectors up to 4 T
- planned detectors up to 6T

Saclay test magnet



- Investigate:

- operation of MP Detectors in B fields
- stability? adverse side effects?
- promise of reduced systematic



First results look encouraging

- stable, predictable operation
- good behaviour in B-fields

Calorimeter: ECAL

Particle Flow needs:

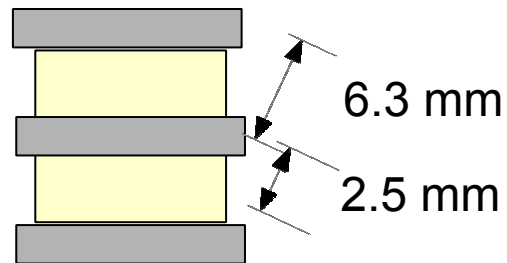
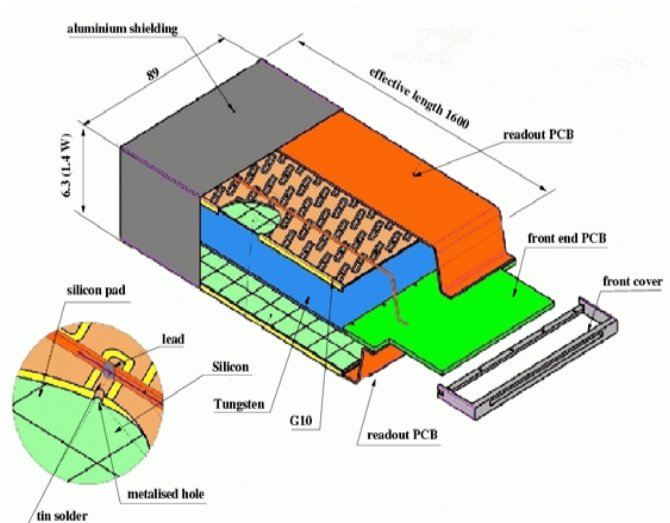
- reasonable energy resolution
- excellent spatial resolution

SI-W sampling calorimeter

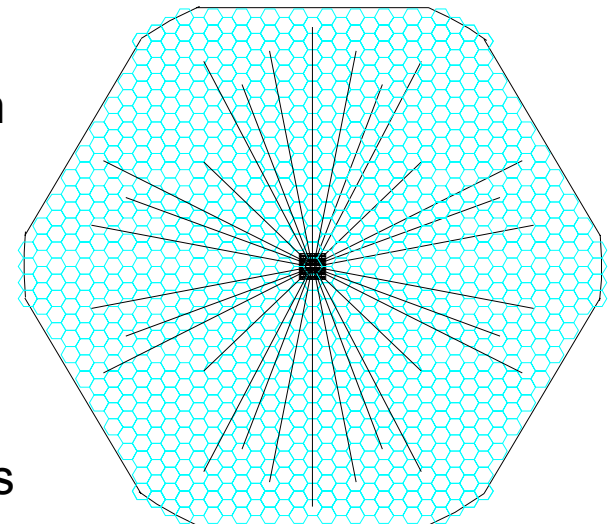
- Tungsten has excellent Moliere Radius (9mm)
- Challenge: minimise the readout gap: dilution

Typical readout cell size close to Moliere Radius:

to



minimise gap:
2.5mm standard
1.5mm ambitious



CALICE layout

6 inch < 152
1,027 < 5mm US SD layout

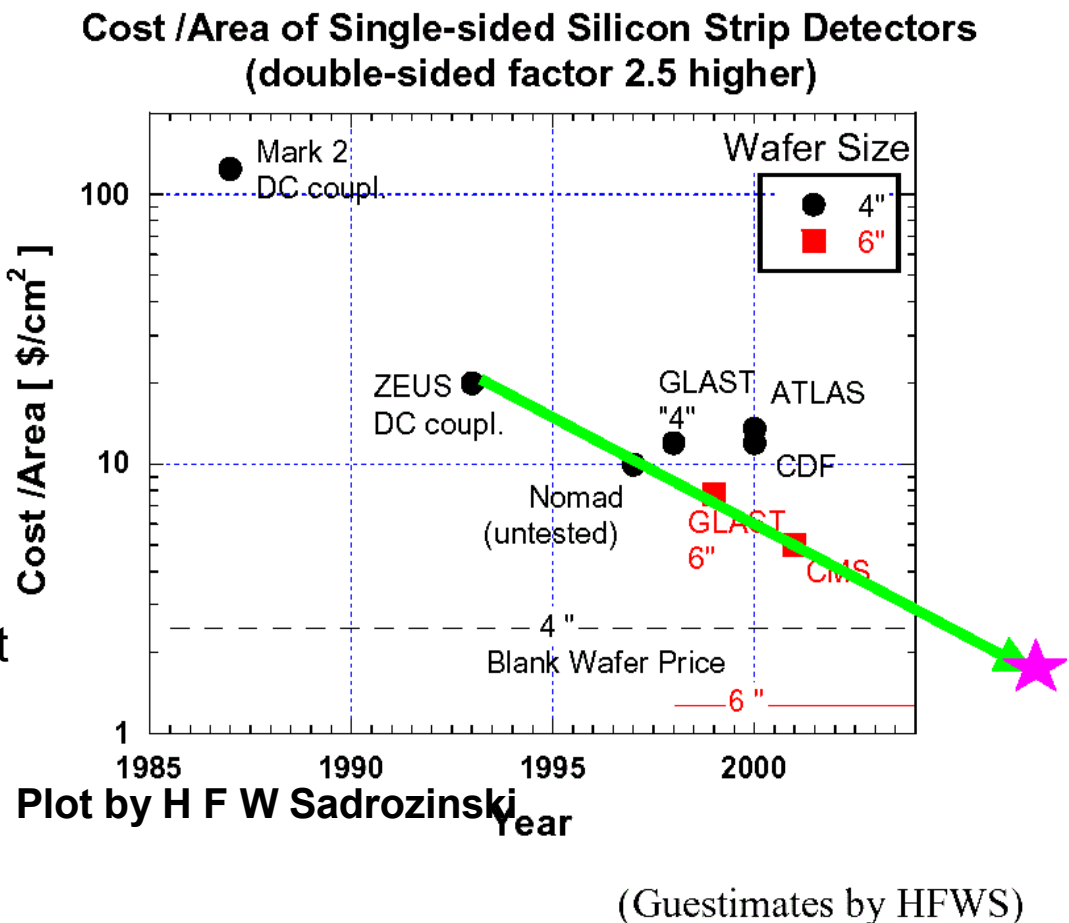
SI-W calorimetry

Cost is major concern for large Si-W Calorimeter

- driven by Si cost
- assume 4\$/cm² → 130M\$
- Si costs continue to drop

readout electronic very important

significant developments under way in EU and US to develop integrated, cheap solutions

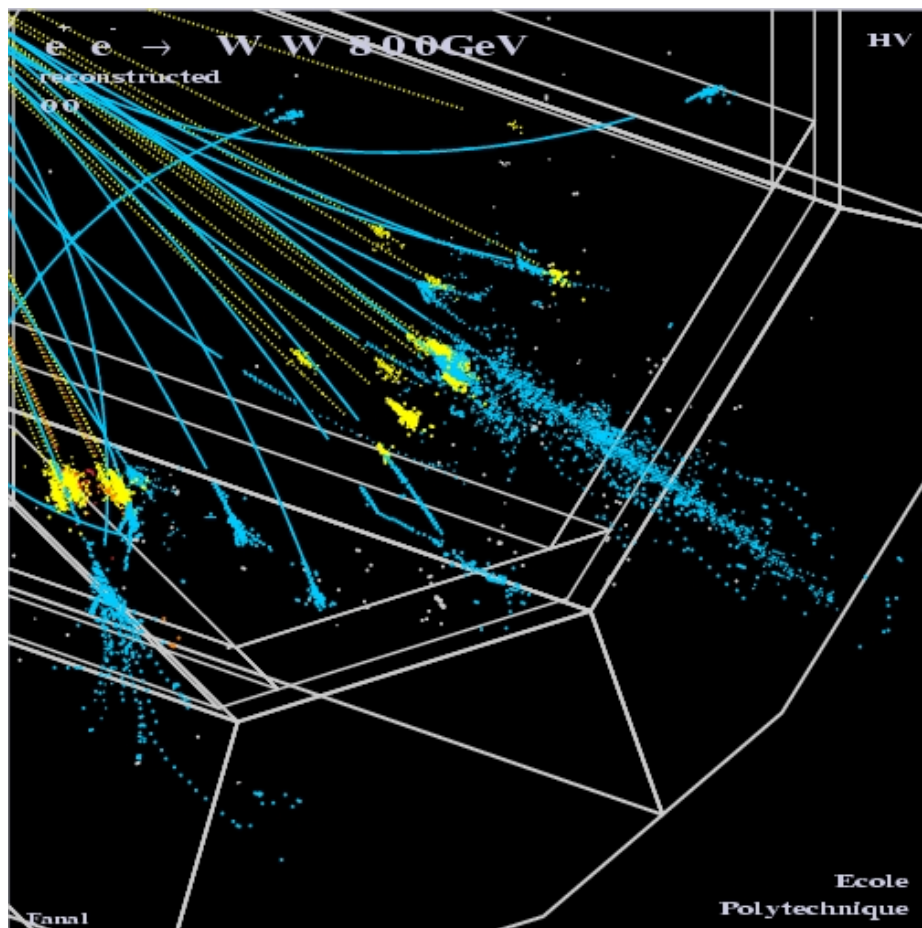


Calorimeter: ECAL

R&D projects:

CALICE collaboration (Europe – US – Asia)

US SD detector groups



prototype assembly of W-plates and readout “drawers” from the CALICE collaboration

develop complete concepts for a large SI-W calorimeter:

- ➡ mechanics
- ➡ optimisation
- ➡ readout
- ➡ integration

Calorimeter: HCAL

New discussion: Digital HCAL calorimeter

- record only the cell which are hit
- no amplitude information
- small cells: imagining HCAL

R&D challenges:

proof of principle
large scale cheap readout
algorithm development

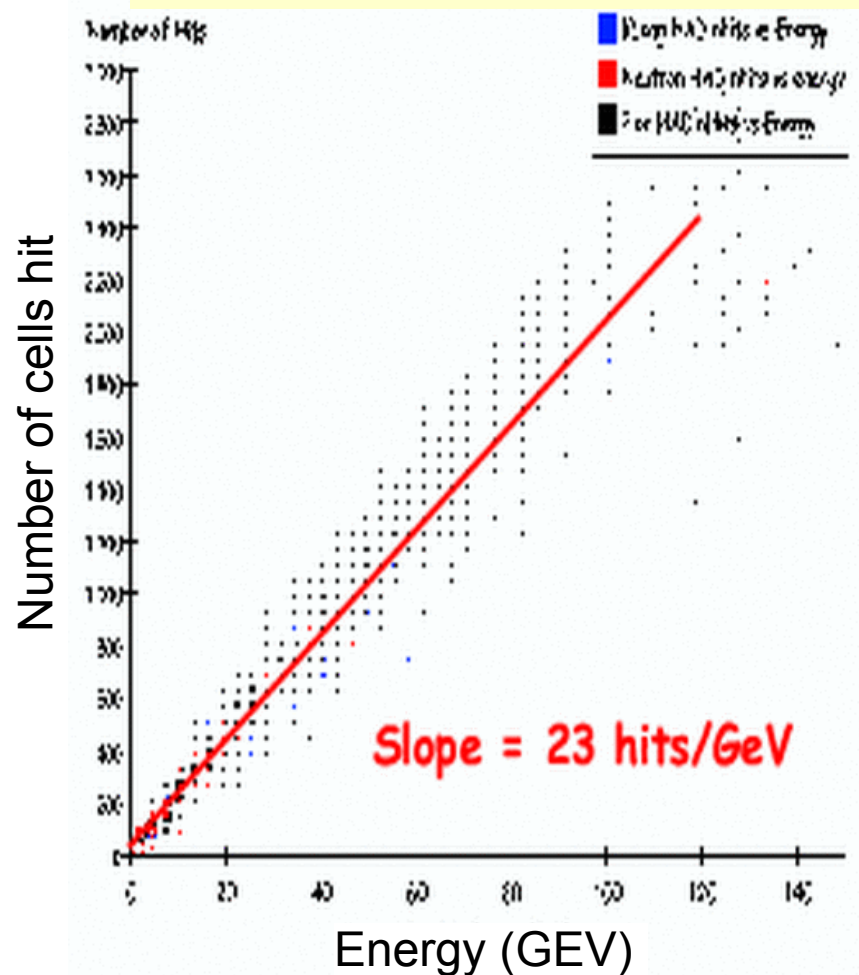
More conventional approach: Tile HCAL

- record the position and amplitude

R&D challenges:

light registration
system optimisation
algorithm development

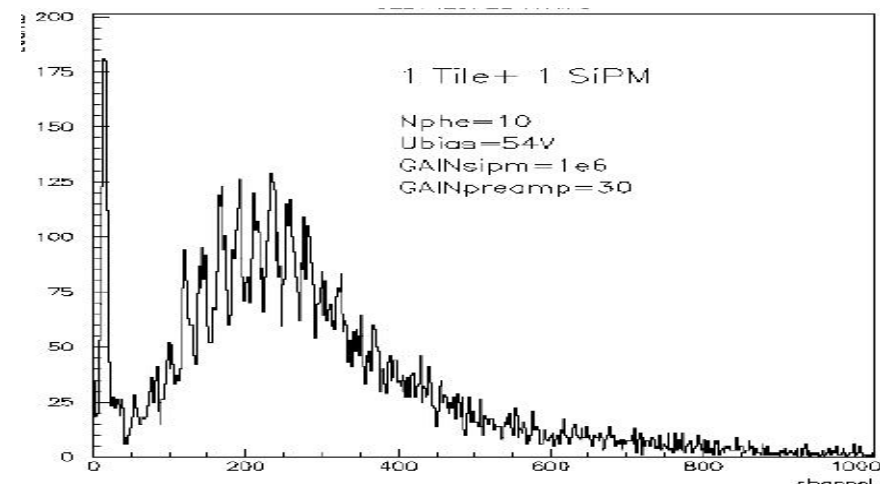
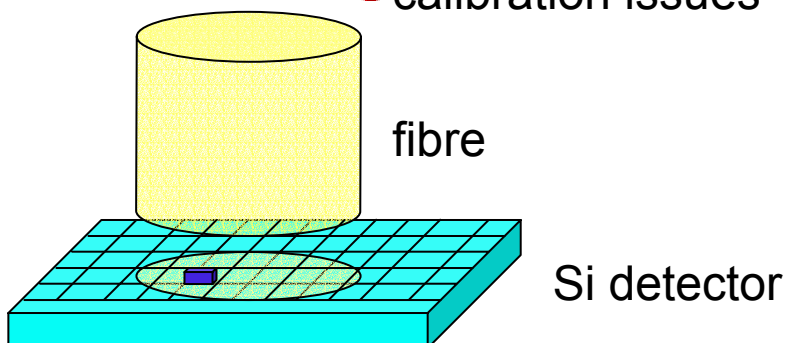
Correspondence between energy and number of cells hit



HCAL: readout technologies

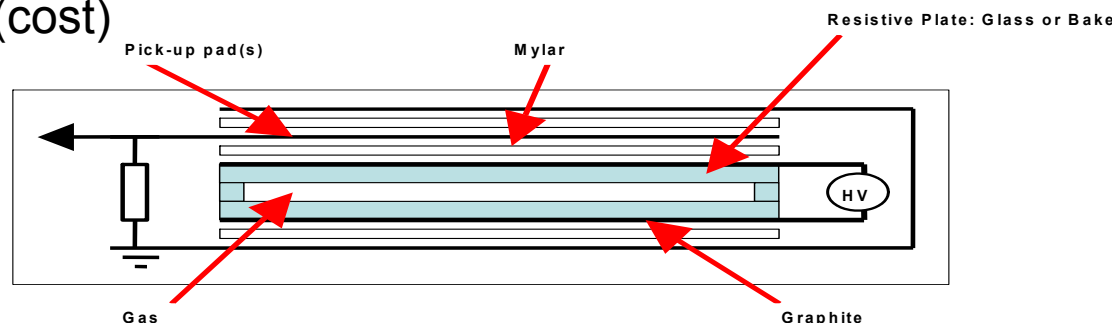
Tile HCAL:

- light registration
 - look at different SI based technologies: have to work in B-field!
 - look at multi-anode photo diodes
 - optimisation of scintillator
 - optimisation of light transport
 - calibration issues



Digital HCAL:

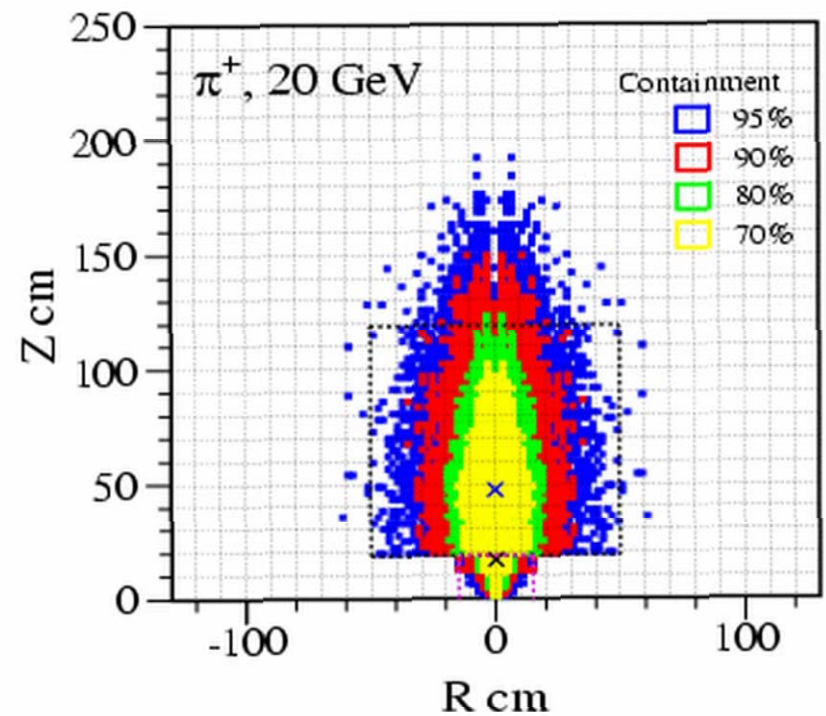
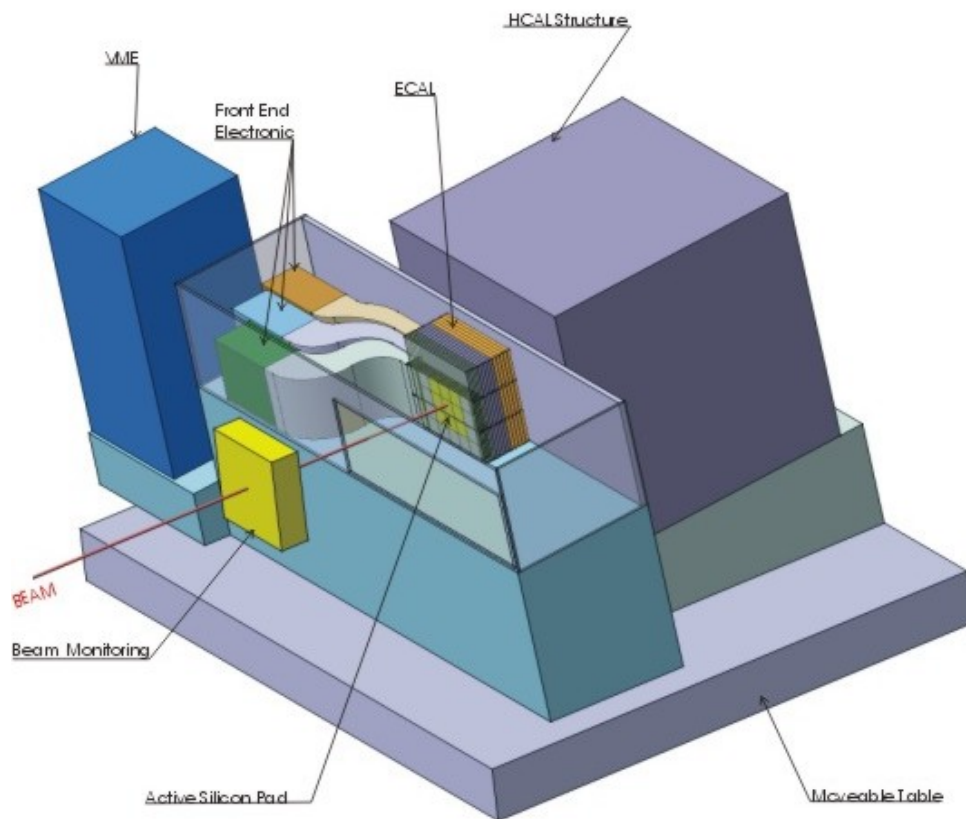
- readout detector: resistive plate chambers?
 - issues of reliability and cost
 - simplification of system (cost)



Calorimeter

Designing a “Particle Flow Calorimeter” stresses the system aspect much more than before

Have to really test the combination of tracker – ECAL – HCAL to judge the system performance



should expect many interesting result over the next few years

Radiation Hardness

- Radiation hardness of SI sensors is major concern at hadron machines:

LHC :	$\Phi (R=4\text{cm}) = 3\text{E}15/ \text{ cm}^2$
Super LHC:	$\Phi (R=4\text{cm}) = 1.6\text{E}16/ \text{ cm}^2$

- LHC: technology available, but serious radiation damage
- SLHC: another factor 5: need to develop radiation hard detectors

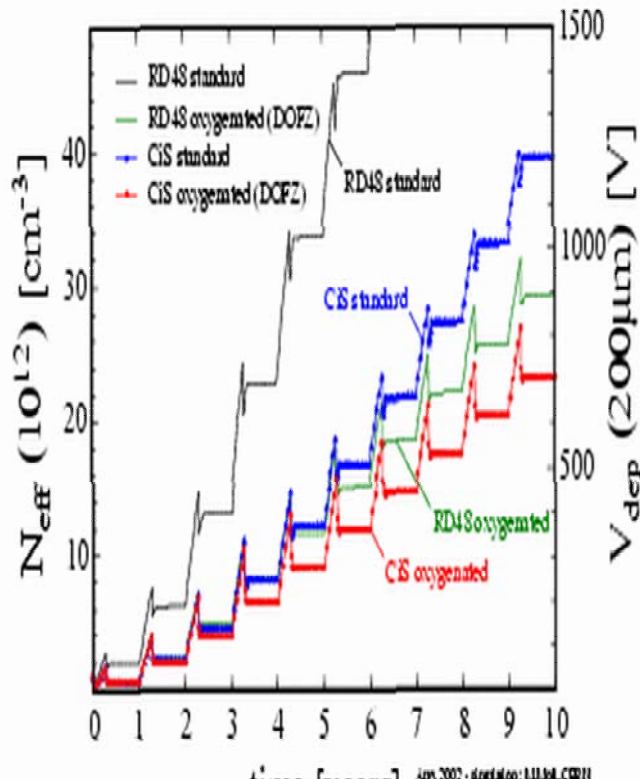
Start a program of systematic studies to

- ➔ understand radiation damage mechanism
- ➔ do focussed engineering of better materials
 - defect engineering
 - new materials (SiC, Diamond, ...)
- ➔ explore detector operation phase space
 - temperatur
 - forward biasing

Si Developments: Rad hard

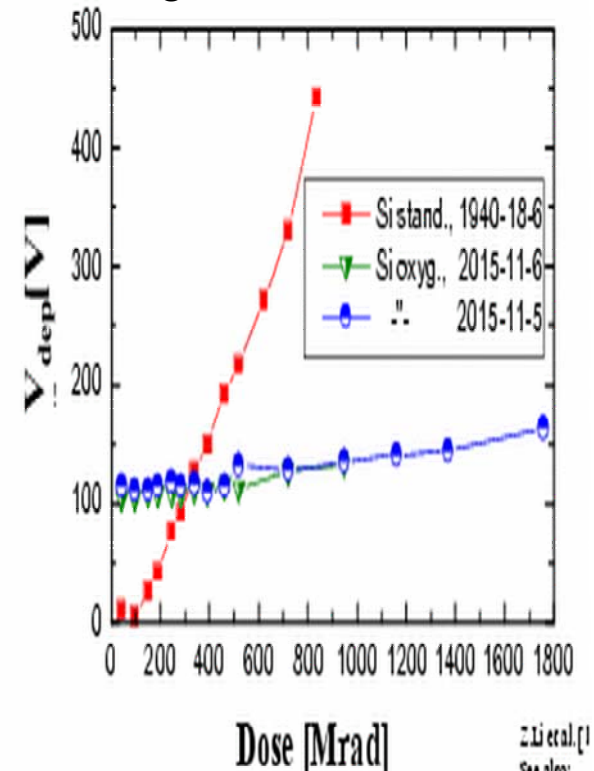
Possible route to better radiation resistance: oxygenation

example: ATLAS B-pixel layer:
projection for different technologies



significant improvement with oxygenated SI

example:
radiation hardness for
gamma irradiation tolerance



spectacular improvement with oxygenated SI

Conclusion

- The next generation of HEP experiments poses interesting challenges for the detector community
- The LC experiment focus on precision
 - stress single particle reconstruction
 - needs whole new philosophy in the overall detector design and concept
 - the concept of particle flow really pushes the detector
- Further developments in the hadron community really stress radiation hardness
- We have interesting years ahead of us trying to meet these challenges and trying to have a realistic and workable detector concept ready in time for a next generation of colliders